Catskill Water Supply

A GENERAL DESCRIPTION

BOARD OF WATER SUPPLY
OF THE CITY OF NEW YORK

JUNE, 1919

Panorama of Ashokan reservoir from High Point mountain. Esopus creek enters the West basin at extreme left of picture. Between the two basins may be seen the Ashokan bridge, the Dividing weir and dike and Upper gate-chamber. Farther to the right is the Olive Bridge dam.

Silver Lake terminal reservoir, in Silver Lake park, Staten Island, looking south, showing the North and South basins with the Middle dike and Gate-chambers between the basins.

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New York's Catskill Mountain Water Supply

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The Catskill water-supply system is the largest which has ever been undertaken. It ranks among the most notable enterprises ever carried out by any city, state or nation. For magnitude and cost and for the variety, complexity and difficulty of the physical problems involved, it stands with the great canals, with the transcontinental railway lines, and with New York's own rapid transit railway system. That portion of this water-supply system which has been completed constitutes about three-quarters of the whole and includes the Ashokan reservoir, an artificial lake 12 miles long, in which are stored the waters of Esopus creek; it includes also the Catskill aqueduct, extending 92 miles from the Ashokan reservoir to the northern boundary of the City, the Kensico storage reservoir near White Plains, the Hill View equalizing reservoir, and the Silver Lake terminal reservoir on Staten Island. There have also been completed, within the City limits, 35 miles of tunnel and pipe-line which serve to deliver the water into the pipes through which it finally reaches the consumer. In order to entirely complete the system, there remains the development of the Schoharie watershed by the construction of the Gilboa dam, which will form the Schoharie reservoir. From this reservoir the water will be diverted through the Shandaken tunnel, now under construction, and thus find its way down the present channel of Esopus creek into Ashokan reservoir. About six years will be required for the completion of this tunnel, which is 18 miles long.

Water from the Catskill sources flows to, and is delivered within, the City by gravity. That is to say, the water flows from the Ashokan reservoir to the City and into the distribution pipes under such pressure that it need not be pumped before it reaches the people who use it. In this respect Catskill water has rendered unnecessary the pumping which was formerly done in Brooklyn and much of that in Manhattan, The Bronx and Richmond. The saving in cost which has thus been effected has been estimated at two million dollars per year.

Catskill water has its origin in the Esopus and Schoharie watersheds. These watersheds, occupying the central and eastern portions of the Catskill mountains, collect the stream-flow from the mountains of sparsely populated areas which they embrace. The Esopus watershed, draining naturally into the Hudson river, has an area of 257 square miles. The Schoharie watershed, draining to the north into the Mohawk river, has an area of 314 square miles. The combined drainage area of these two sources is therefore 571 square miles, and it is conservatively estimated that even during a series of extraordinarily dry years, more than 500 million gallons of water daily can surely be drawn. The geology of the areas included within the Esopus and Schoharie watersheds is entirely sandstone and shale, and the water, in consequence, is of an unusual degree of softness. The small population also results in a water free from pollution. The greater part of the water from these two drainage areas will be stored in the Ashokan reservoir, the balance being held in the Schoharie reservoir, the construction of which will now be undertaken.

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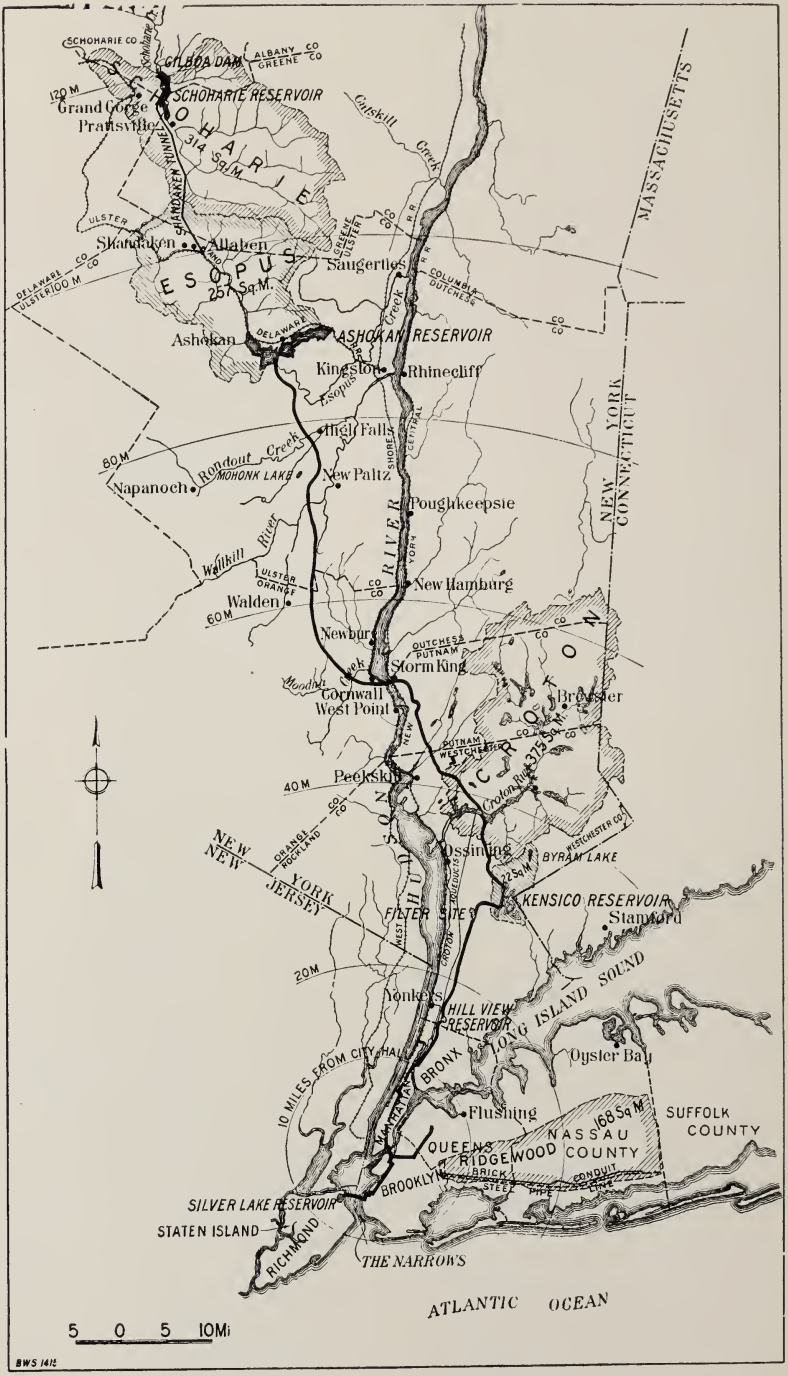


Map of the Catskill water-supply system showing its relation to the Croton and Ridgewood systems.

The Catskill aqueduct, leading from the Ashokan reservoir to the City, will, when finally completed, have a capacity of not less than 500 millions of gallons per day. On account of the rugged and diversified character of the country traversed by the aqueduct, several different types of construction were used. Typical details of these several types of construction are shown on the plate printed on page 20. The type known as cut-and-cover aqueduct was constructed wherever the natural surface of the ground was close to the hight at which the water in the aqueduct would naturally flow. When it became necessary to pierce through a mountain, the type designated as grade tunnel was used. Where it was necessary to cross under a long, deep valley, such as that of the Hudson river, the type indicated as pressure tunnel was used. But where the valley was shorter and not as deep, steel-pipe siphons, laid just below the surface of the ground, were employed. For the supply of Staten Island, a cast-iron pipe laid in a trench under the bottom of the river was employed. This pipe was made up of 12-foot lengths with a flexible joint at each end.

In order that the quality of the water delivered should be of the very best, aeration basins, which consist of a large number of small fountains, have been constructed at both the Ashokan and the Kensico reservoirs. The purpose of these fountains is to throw the water into the air and convert it into a fine spray so that the disagreeable tastes and odors which, at some seasons of the year may occur, will be eliminated. For insuring the sanitary quality of the water a chlorinating plant was installed at the Kensico reservoir and all of the water at that point is sterilized and rendered entirely pure.

The foregoing is a brief statement and skeleton description of the Catskill water-supply system as a whole. The various features, including a brief historical statement and outline of the organization which conducted and is now carrying on the work, will be found in the following pages.

THE PERIOD OF PREPARATION

Preceding the active period of construction there was necessarily a long period of preparation. Passing over the informal suggestions which appeared from time to time and which looked toward the increase of the City's water-supply, it may be said that the final campaign began with a report which was presented on March 15, 1897, to the Manufacturers' Association of Brooklyn, by a special committee of which Charles N. Chadwick was Chairman. This Committee had made an extended investigation of the problem because of the frequently recurring need for more water in that borough. Four recommendations were made in this report: That all plans for water should contemplate a Greater New York; that to finance the project the State Constitution must be amended so that the water debt would be separate from the Constitutional debt limit; that the project should be administrated by a Commission charged from start to finish with the entire responsibility for the work and that the City's needs for a period of 50 years should be considered.

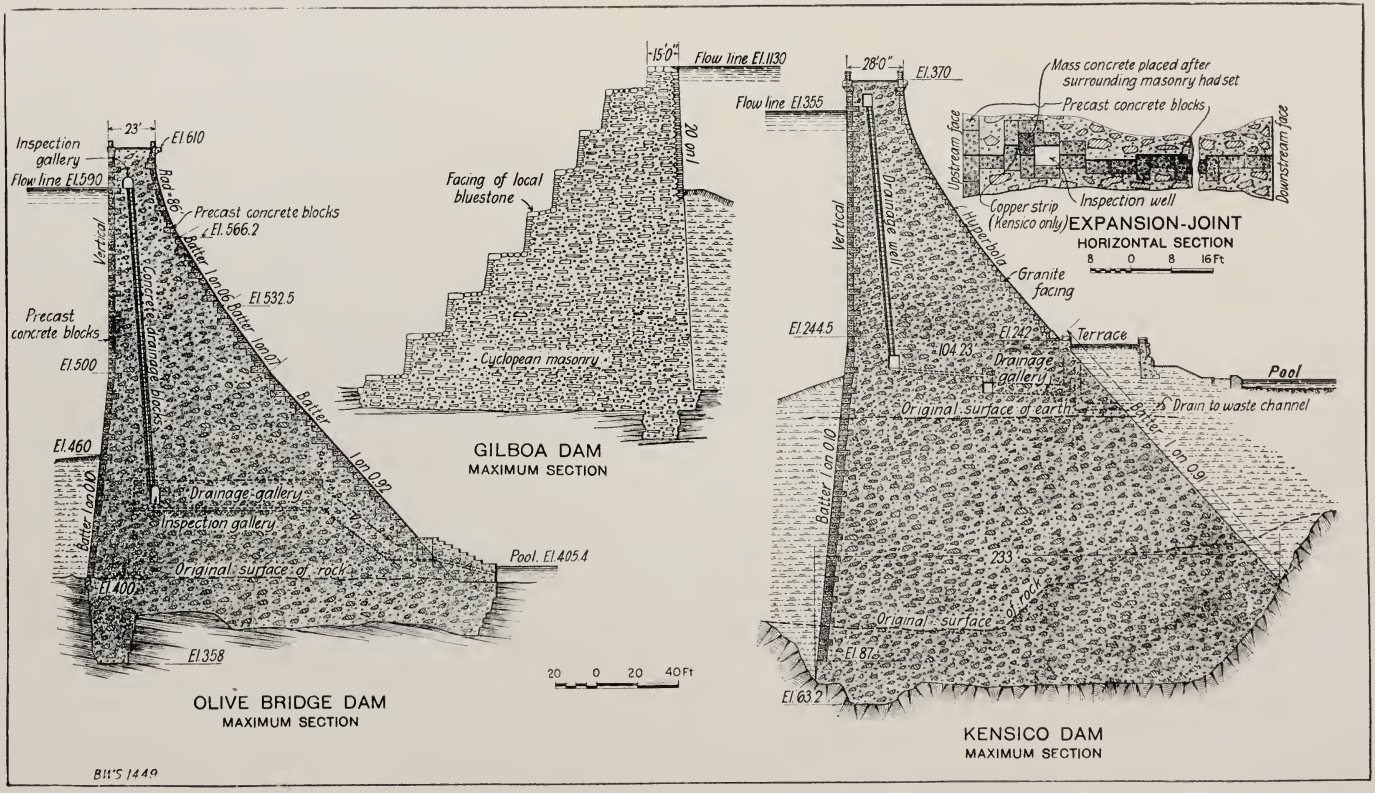
In 1901, following the agitation by this Association, a bill, prepared by its Committee, was introduced in the Legislature having for its object the creation of a Commission empowered to add to the water-supply of the City. This bill failed of passage and similar bills were introduced successively in 1902, 1903 and 1904. In 1898 a consolidation of the municipalities about the harbor within New

Ashokan reservoir, showing portions of the Beaver Kill and Dividing dikes, the Lower and Upper gate-chambers, Ashokan bridge, and the Dividing weir under the bridge. The East basin is in the background.

York State was consummated, and in the Greater City of New York there was united a population of 3,250,000. Soon thereafter it was proposed that a private company should supply the City from the Ramapo river and the Catskill mountains on terms which would have been very profitable to the company. This attempted exploitation of the City led Comptroller Bird S. Coler to have a thorough investigation made and, for this purpose, he appointed John R. Freeman, whose report in 1900 set forth the need for an additional supply and pointed out those sources from which it could be obtained. The Ramapo scheme being exposed and the community being roused, various civic organizations became active, especially the Merchants' Association, which engaged a number of engineers to conduct independent investigations and whose reports were published in August, 1900. Commissioner of Water Supply Robert Grier Monroe, in December, 1902, appointed William H. Burr, Rudolph Hering and John R. Freeman as a Commission on Additional Water Supply. This Commission was charged with the investigation of the needs of the various boroughs of the City, of means for curtailing waste, and with the duty of recommending the most available sources and the best means of their development. This Commission in November, 1903, submitted its report, which recommended the development of the Esopus watershed in connection with certain sources of supply lying east of the Hudson in Dutchess county. The following Legislature, however, enacted laws which prohibited the City from utilizing most of the sources east of the Hudson which had been recommended by the Commission. The Commission had not reported favorably on the filtration of water from the Hudson river; the Aqueduct Commissioners were putting forth every effort to develop the Croton watershed as far as practicable, and the Department of Water Supply was doing its best to extend the underground systems in Nassau county and in the immediate background there was ever present the fear that a dangerous shortage of water might at any time eventuate.

This, in short, was the situation at the end of the year 1904. Eight years had been spent in collecting information and in educating the people and the State and City governments. One very important preliminary step had, however, been taken; in 1904 an amendment to the State Constitution had been ratified, removing capital expenditures for water-works from within the scope of the municipal debt limit. Meanwhile, the population of the Greater City had increased to four millions and was growing at the rate of 115,000 per year. The demand for water was rapidly going ahead of the safe yields of the supplies available and severe shortages had barely been escaped on more than one occasion. Amid these conditions the City again appealed to the Legislature, and, at the beginning of 1905, the McClellan Bill was introduced. After some vicissitudes, having the combined backing of the City administration and the civic organizations, this bill became a law by signature of Governor Higgins, on June 3, 1905.

In order to safeguard the interests of all communities of the State and to control the utilization of the State's water resources, the Legislature coincidentally passed a companion bill creating a State Water Supply Commission. These bills, approved on the same day, became, respectively, Chapters 724 and 723 of the Laws of 1905. From time to time, as the years passed, these laws were amended and other special legislation was enacted. The duties of the State Water Supply Commission were merged with those of the State Conservation Commission. New York City was required to create and maintain a special force of constabulary for the protection of the communities in which its construction operations were being



Cross-sections of the masonry dams of the Catskill water-supply system. Flood waters will flow over the top of the Gilboa dam but not over the Olive Bridge nor the Kensico dam.

carried on. Certain municipalities were given rights to take water from the new aqueduct. Labor laws were made more drastic and statutes relating to the liability of employers were enacted. Payment for indirect damage to land and property not actually taken for the needs of the water-supply and for the loss of business and wages was provided for. Under these various prescriptions and requirements the work was rapidly and energetically prosecuted so that by the end of 1917 the first step in the development as a whole was completed and 250 millions of gallons of Catskill water were daily available for use. Since that time the system has in fact been drawn upon for an average of more than 400 million gallons daily.

THE ORGANIZATION

The law provided that the three commissioners of the Board of Water Supply should be appointed by the Mayor and should be removable only "for incompetency, or misconduct shown after a hearing, upon due notice, upon stated charges. * * *." In this manner continuity of administration and policy in the prosecution of the undertaking was assured. On June 9, 1905, Mayor George B. McClellan appointed as members of the Board of Water Supply, J. Edward Simmons, who was elected President, Charles N. Chadwick and Charles A. Shaw. Upon the resignation of Mr. Simmons, Mayor McClellan appointed John A. Bensel, who was elected President on January 31, 1908. Mr. Bensel's resignation, at the end of 1910, was followed by the appointment by Mayor William J. Gaynor of Charles Strauss, who was elected President, February 8, 1911. Mr. Shaw resigned on January 12, 1911, and his place was filled by the appointment of John F. Galvin on January 23, 1911. Mr. Strauss resigned March 19, 1918, and Mayor John F. Hylan appointed L. J. O'Reilly to the vacancy on April 23, 1918, on which day Mr. Galvin was elected as President of the Board. At this time the Commission is therefore constituted as follows: John F. Galvin, President; Charles N. Chadwick and L. J. O'Reilly.

It was realized at the very beginning that there were certain fundamental policies to be determined upon. They were: Unity of organization, thoroughness, efficiency, economy, continuity of plan, and speed. These principles were worked out, and exactly four months after its appointment, on October 9, 1905, the Board of Water Supply submitted to the Board of Estimate and Apportionment for its approval a map, plan and estimate of cost as a complete project for obtaining water from the Catskill mountains, setting a standard of speed which has been continuously maintained.

The functions of the Board were executed through several bureaus, the head of each of which reported directly to the Commissioners. The Administration bureau was headed by the Secretary, the present incumbent being Benjamin F. Einbigler. This bureau had charge of the official records, accounts, purchasing of supplies, and of other matters of general administration. H. C. Buncke has been Auditor of the Board since its organization. The Real Estate bureau was charged with the acquisition of property by direct purchase, with the adjustment and payment of taxes on property acquired by the Board, and with all similar related matters. The lands necessary for the purposes of the reservoirs and aqueducts were secured through condemnation proceedings, as provided in the statute. In

With nearly 25,000 laborers in camps during construction, the Aqueduct Police protected communities near the water-works. Their presence alone was a deterrent to those criminally inclined. They maintained order, protected person and property and enforced sanitary and other rules, as well as local ordinances and laws governing intoxicants, concealed weapons, speeding, etc.

these proceedings the City was represented by the Corporation Counsel and by special counsel appointed by him.

To the Police bureau, now under the direction of Commissioner Galvin, was assigned the protection of "the inhabitants of the localities in which any work may be constructed under the authority of this act and during the period of construction, against the acts or omissions of persons employed on such works or found in the neighborhood thereof."

The Bureau of Claims, of which John H. McManus is now Chief, was charged with the duty of collecting facts relating to claims for indirect damage, claims for damage to established business arising from the creation of the new water system, and many other closely related matters. This bureau coöperates with the Corporation Counsel in the investigation and preparation of cases prior to their trial before the Commissioners of Appraisal.

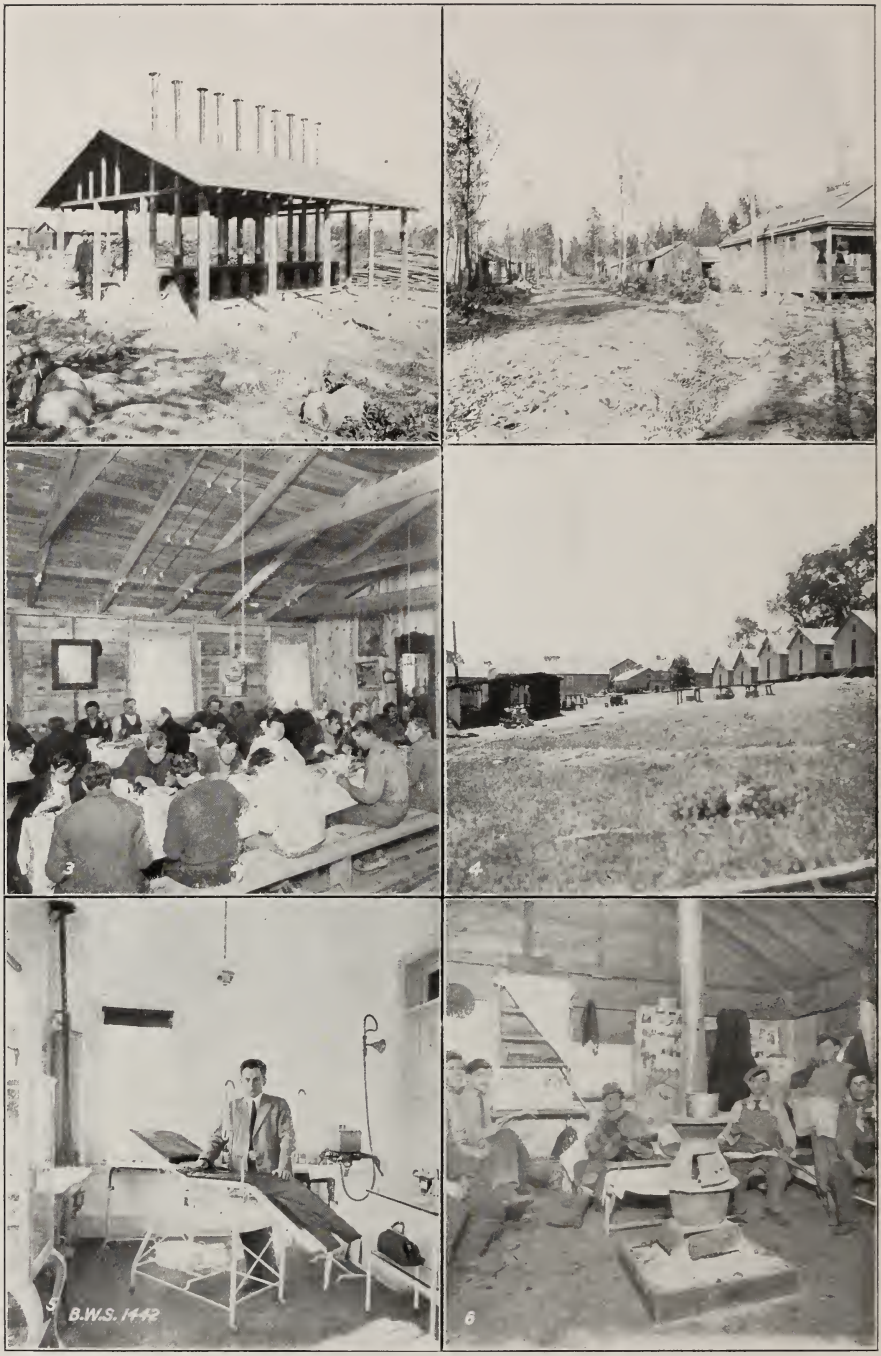
During the summer of 1905, John R. Freeman, William H. Burr and Frederic P. Stearns were appointed Consulting Engineers and J. Waldo Smith was placed in charge of the Engineering bureau as Chief Engineer. To this bureau was committed the duty of making all surveys and investigations, the preparation of estimates, designs, contracts and reports, the inspection and test of supplies, equipment and materials, the supervision of construction and of all other engineering matters relating to the project as a whole. This bureau was divided into departments, which were again divided into divisions and sections, the department engineers reporting directly to the Chief Engineer. Each department was divided into from four to six divisions, each division having supervision of construction work amounting in value to from five to nine millions of dollars.

The work of the Board of Water Supply is being done under the 8-hour law. From the beginning, the problems of sanitation, of contentment and of efficiency on the part of all workers were considered. Contracts along these lines were carefully drawn. Camp schools to teach the English language to the workingmen were established, and through the medium of a common language misunderstandings were removed. The human side of the workingman was considered. There were no strikes and the death rate from all causes was less than one-half that of the corresponding rate in New York City. In addition to this, each individual in all departments of the work has recognized a certain freedom which has stimulated him to take the initiative in the work of his particular department with a sense of responsibility and with energy, faithfulness and efficiency for the good of the whole, the result of which has developed the wonderful *esprit de corps* of the organization.

CONTRACTS

The Board is required by law to do practically all the construction by contracts based on bids received after public advertisement. The work was divided into a number of parts, mainly along geographical lines, and contracts were entered into with companies who were familiar with the class of work involved, to perform the actual construction and furnish such necessary materials as were not found on the site of the work. There have been 24 major contracts, each amounting to between one and twelve million dollars; 40 amounting to between $100,000 and $1,000,000; while 74 minor contracts have been let.

During the years of active construction the contractors' daily forces ranged from a minimum of 500 to a maximum of 17,243, counting only the men actually



Contractors' Camps—(1) Outdoor stoves at Camp Hill View. (2) Chadwick avenue at "Camp City", at Ashokan. (3) Mess hall, Camp Hill View. (4) Camp Blakeslee near Croton lake. (5) Operating room in contractor's hospital. (6) Recreation at close of legal 8-hour day.

and directly at work on the City's structures. If the large number of men in the cement mills, metal and other manufactories, scattered throughout the country producing materials which were directly used in the construction work are included, the daily force would have totaled a maximum of about 25,000.

THE ESOPUS DEVELOPMENT

The Ashokan Reservoir

The Ashokan reservoir is located in Ulster county, about 14 miles west from the City of Kingston. Its cost, together with that of the necessary appurtenant works, including the relocation of highways and of the Ulster and Delaware railroad, was nearly $20,000,000. This reservoir has a water surface of 8,180 acres and an available capacity of 128 billions of gallons, a quantity sufficiently great to cover all of Manhattan Island to a depth of 30 feet, its area being equivalent to that of Manhattan below 110th street. The principal structures which form this reservoir are the Olive Bridge dam, built of masonry, across the Esopus creek, the earthen dikes or dams which close in the gaps between the hills forming the natural walls of the reservoir, the Dividing dike and weir, which separates the reservoir into two basins, and the Waste weir, over which the surplus flood waters may be safely discharged. The Ashokan reservoir is divided into two parts, which are known as the East basin and the West basin, the full water surface elevation of the West basin being at 590 feet above mean tide at New York, while the East basin is at an elevation 3 feet lower. This division into two basins was made so as to provide greater flexibility of operation and thus at all times insure the drawing of water from that part of the reservoir in which the conditions are the most favorable.

The masonry portion of the Olive Bridge dam is founded on solid ledge-rock and was built of cyclopean concrete faced with smoothly finished concrete blocks. At each end the masonry section is flanked by earthen dikes built of selected earth which was spread in thin layers and thoroughly compacted by rolling. The bottoms and slopes of the reservoir basins were cleared of trees, brush and all other objectionable matter; 40 miles of new highway were constructed around the reservoir. This work required the construction of ten new bridges, one of which has a span 200 feet long and one of which has a total length of 1,120 feet. The relocation of the Ulster and Delaware railroad required the construction of 11 miles of new road-bed and track.

The work on the Ashokan reservoir required the services of an army of laborers, which force attained a maximum of 3,000 men, who lived, many of them with their families, in a camp near the work. In order to serve a community thus formed, sewerage and water-supply systems were constructed, streets built, electric lights and telephones furnished; National and savings banks were established, a hospital was provided, and police and fire protection were furnished; schools for children and for the men on the work were established and quarters for the holding of divine service and for a Y. M. C. A. were provided. The maximum population in the main camp was approximately 4,500. On the completion of the work the camp was so thoroughly removed that scarcely a trace of it can now be found. In connection with the construction of the Ashokan reservoir there

A group of highway bridges, all of reinforced concrete. (1) Esopus bridge across the creek just above the westerly end of the reservoir; five spans, 67½ feet. (3 and 5) Spillway bridge, 175-foot span, across the Waste channel through which flood waters are discharged which pass over the Waste weir of the Ashokan reservoir. (2) Traver Hollow bridge over a small stream entering the West basin of the Ashokan reservoir; a 200-foot, 3-hinged arch. (4) Ashokan bridge crossing the reservoir between the East and West Basins; 15 spans of 67½ feet. (6) Rye Outlet bridge across the Kensico reservoir; five spans of 127 feet.

were built approximately 30 miles of railroad on which were operated 33 locomotives and 580 cars. Other plant used included 60 derricks, 7 cableways, 16 steam rollers, 19 steam shovels, besides the concrete mixing outfits, the air-compressor plants, the machine-shops, and the many other items necessary for the production of a completed piece of work.

The Kensico Reservoir

The Kensico reservoir, in Westchester county, 30 miles north from the City Hall, was designed to contain sufficient Catskill water for maintaining the supply over a period of several months. It serves as a storage reservoir, so that the flow to the City will not be interrupted while the 75 miles of aqueduct between it and the Ashokan reservoir are at any time out of service. This reservoir is formed by the Kensico dam, across the valley of the Bronx river, about three miles north of White Plains and 15 miles north of the Hill View reservoir. Its capacity is 29 billions of gallons, and its surface elevation is at 355 feet above mean tide at New York. The area of its water surface is 2,218 acres and the marginal protective strip around its entire circumference is in few places less than 500 feet wide. The Kensico dam is one of the great masonry structures of the world. It contains altogether nearly one million cubic yards of masonry—about one-third that which the Egyptians placed in the great pyramid. However, of the large amount of masonry in this dam only about one-third is visible above the surface of the ground. At the point of greatest hight it rises 307 feet above the rock foundation on which it rests. A new highway system, rendered necessary by the construction of the Kensico reservoir, embraced the construction of 15 miles of road on which were a number of bridges, one of them a reinforced-concrete structure of five arches, each about 127 feet long. This bridge carries the highway over an arm of the reservoir and the roadway at the center is 107 feet above the reservoir bottom.

Catskill water enters the Kensico reservoir near its upper end and is drawn from the lower end through a system of gates located in chambers about one mile north from the Kensico dam. At this point provision is made for controlling the rate at which the water is drawn, for screening and for sterilizing it with liquid chlorine. Here also has been provided a large aeration basin in which the water is thrown into the air through 1,599 nozzles. This operation results in thoroughly mixing the water with air and thus aiding its purification.

The Kensico dam is located practically on the site of a small original dam which formed the old Kensico reservoir in which were stored the waters of the Bronx and Byram rivers. This old reservoir was very much smaller and lower than the present one and it has been entirely obliterated. The Kensico dam is a gravity masonry structure built of cyclopean masonry faced on its up-stream side with concrete blocks and with granite masonry on its down-stream face. In order to provide for the movements which result from seasonal changes of temperature, the dam is divided into sections by expansion-joints spaced about 80 feet apart.

The accompanying photographs indicate the architectural treatment which was developed on the down-stream face of the dam. Local stone was used for the facing of the dam and an effort was made to secure as rough and rugged an appearance as was consistent with the principles of the adopted design.

Preliminary surveys for the Kensico reservoir were begun in May, 1906, and the contract for the construction of the dam was awarded in December, 1909, the amount of the contract being $8,006,300. It was required that the work should

Kensico dam and portion of the reservoir, with the Lower Effluent chamber in right background.

be entirely completed by February, 1920. Due, however, to the exceptional manner in which the work was prosecuted, the dam was completed to its full hight nearly four years sooner than was thought possible when the contract was prepared. The maximum number of employees on the work was about 1,500. These men lived, many of them with their families, in a camp below the site of the dam. This camp was provided with sewerage and water-supply systems, and the best of care was taken of the sanitary situation. Schools for children and men were provided and a hospital was established.

Power necessary for the varied operations entering into the construction and execution of the work was transmitted from power-houses of The New York Edison Company, in New York City, over a transmission-line constructed especially for this purpose.

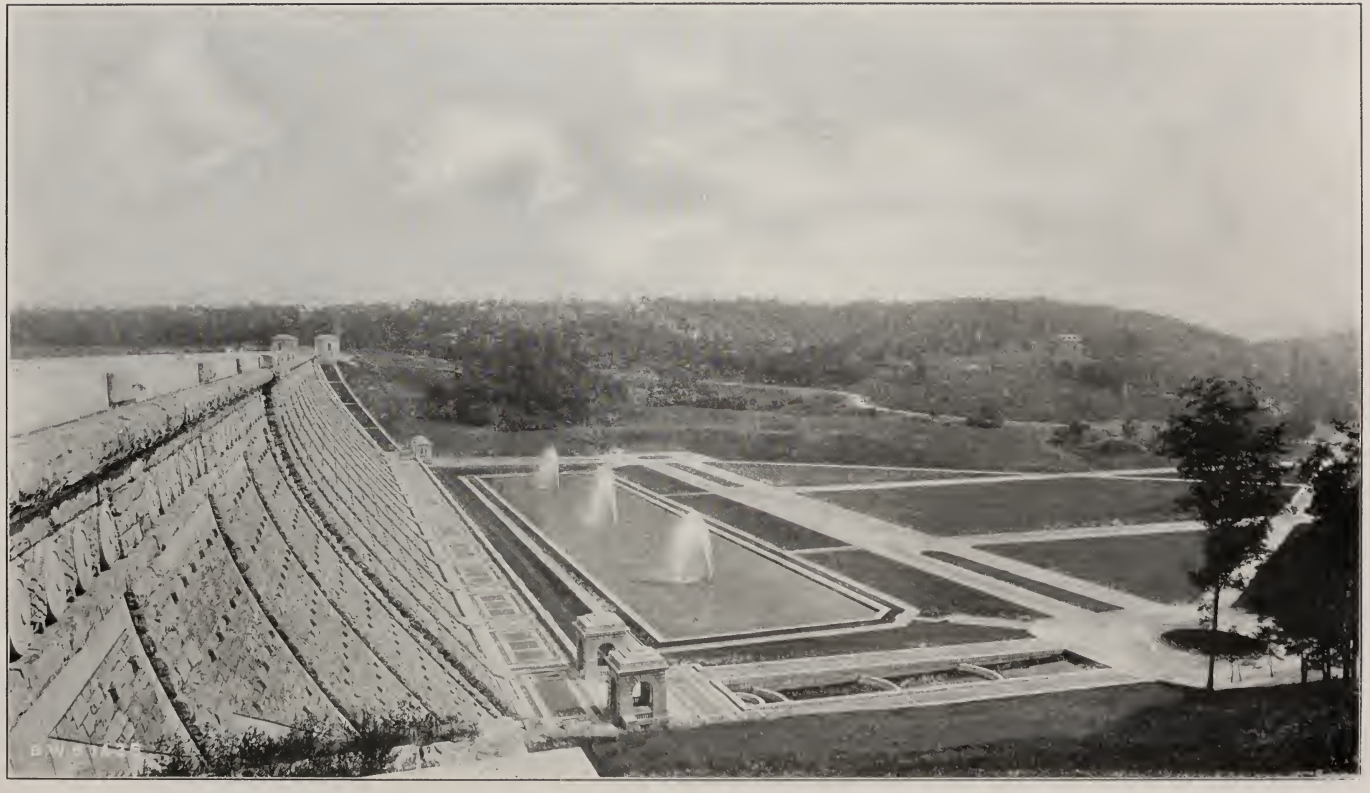
The total volume of masonry in the dam is 965,000 cubic yards. The maximum amount placed in one month reached 84,450 cubic yards in August, 1914, while in the season of approximately eight working months 485,000 cubic yards were put in place. There were used in the dam 897,000 barrels of Portland cement.

The Hill View Reservoir

The Hill View reservoir is located on the highest available ground in the City of Yonkers, just north of the New York City line, and 15 miles south of Kensico reservoir. It is an uncovered artificial reservoir of the earth embankment type, and is lined with concrete. It has a depth of 36½ feet and a water-surface area of 90 acres. It holds 900 million gallons, its function being to equalize the difference between the use of water in the City, as it varies from hour to hour throughout the day, and the steady flow in the aqueduct. Its outlet is the vertical Downtake shaft of the single large distribution tunnel which goes under The Bronx and Manhattan to Brooklyn and the pressure of the water delivered to the City through that tunnel is due to the great elevation, 295 feet above sea-level, of the water surface in Hill View reservoir. The Catskill water is delivered to the City, therefore, 161 feet higher than Croton water. The reservoir is divided into two basins by a wall 2,740 feet long that contains the by-pass aqueduct, so that either one or two basins may be used, or be by-passed whenever required, directly into the City tunnel. The contract for its construction, including some tunnel work, was awarded in December, 1909. It was first filled December 29, 1915, the cost of the completed work being $3,212,900.

The Silver Lake Reservoir

This small distribution reservoir for Staten Island is about 2,400 feet long by 1,500 feet wide, uncovered and formed by the natural ground and by artificial embankments with core-walls. It is not lined with concrete. A dividing dike paved with concrete divides the reservoir into two basins, holding together 435 million gallons. From a gate-chamber built in this dike, reinforced-concrete conduits extend to the boundary of the reservoir, and cast-iron pipes connect these with the Narrows siphon and with the Staten Island service mains. It has a depth of 35 feet and the water surface is 228 feet above sea-level.



Down-stream face of Kensico dam and the park below, looking from the Pavilion at the west end of the dam across the Terrace at the base of the dam, the Pool and the Cascade basins.

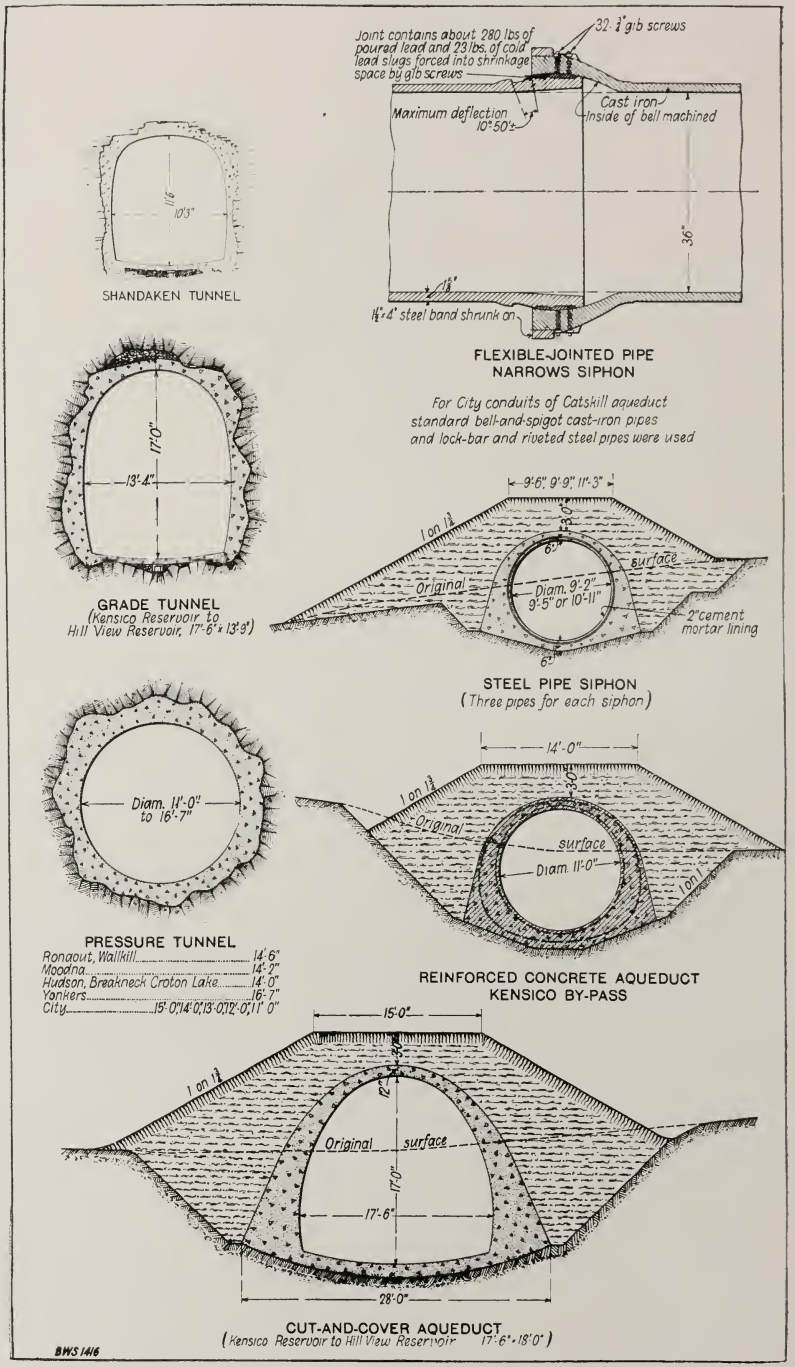
The Aqueduct

As has been pointed out, four distinct types of conduit or aqueduct were adopted to meet the varying physiographic features of the country traversed by the aqueduct from the Catskill mountains to the City. Where the topography and the elevation of the ground permitted the cut-and-cover type was used. This type was the least expensive, and was built for a total of 55 miles. The construction consisted of excavating a trench, in the bottom of which a floor or invert of concrete was placed. Resting upon the sides of the invert and bonded to it, the side-walls and arch of concrete, without steel reinforcement, were poured between steel forms, to the desired horseshoe shape. From outside to outside of the masonry required a trench 28 feet wide or about as wide as between curb to curb of a New York cross-town street. Sufficient earth was taken from the trench to form a protective grassed covering of at least three feet over the concrete. That portion north of Kensico reservoir is 17 feet high and 17 feet 6 inches wide, inside dimensions, and has generally a slope of about 1.1 feet per mile, which is sufficient to allow the desired flow of water to pass by, nearly although not completely, filling the aqueduct. Between Kensico and Hill View reservoirs the cross-section was enlarged to a hight of 17 feet 6 inches and a width of 18 feet.

Where hills or mountains were encountered, and it would have been impracticable or uneconomical to circumvent them, tunnels were driven and lined throughout with concrete without steel reinforcement. This, the grade-tunnel type, acts similarly to the cut-and-cover type, in that the water flows in it as it would in an open channel. It, also, is a horseshoe shape, but of lesser dimensions and steeper slopes. There are 24 of these grade tunnels, aggregating 14 miles; they are 17 feet high and 13 feet, 4 inches wide inside.

Where valleys were encountered, it was not possible to carry the aqueduct along at the natural elevation or gradient which the water would take, and in such cases types were adopted which would withstand the bursting pressure produced by placing the aqueduct below the hydraulic gradient. In the larger valleys the pressure-tunnel type was used, which consisted of a circular tunnel driven deep enough below the valley bed so that the rock would withstand the bursting pressure. The tunnel is connected at either end to the aqueduct by vertical circular shafts also in suitable rock. Tunnels and shafts are lined with concrete without steel reinforcement throughout and all seams around the concrete and in the rock filled by forcing in under pressure thin grout made of Portland cement, fine sand and water. Drainage shafts were constructed so that each pressure tunnel can be unwatered for inspection, cleaning and repair. Besides the end and drainage shafts other shafts were sunk to aid in excavating and lining the tunnels. These construction shafts were afterwards sealed with deep concrete plugs just above the tunnel and partially refilled, near the top, with rock debris and earth supported on concrete arches across the shaft. There are seven of these pressure tunnels, totaling 17 miles, varying in diameter from 14 feet to 16 feet, 7 inches.

The most important of the valleys to be crossed was that of the Hudson river, where the tunnel was driven in granitic rock at a depth of 1,114 feet below sea-level. This 14-foot tunnel extends from a shaft at Storm King mountain on the west bank to another shaft on the east side of the river at Breakneck mountain, a distance of 3,022 feet.



Standard types of conduit used in the Catskill aqueduct. (In addition to the above, riveted and lock-bar joint steel pipes and bell-and-spigot cast-iron pipes of ordinary types were used.)

The construction of cut-and-cover aqueduct. In the foreground the concrete invert, or bottom, is being placed and immediately back of it are the steel inside forms, followed by a section where the steel outside forms also have been placed ready to receive the concrete, brought on the railroad and lifted into place by the locomotive crane. In the background is completed aqueduct ready to be covered with earth embankment.

Pressure tunnel: (1) drilling "heading" and "bench"; (2) loading dynamite into the holes; (3) removing the "muck"; (4) hauling "muck" out and concrete in; (5) placing concrete lining around steel forms; and (6) grouting crevices in the rock back of the lining.

Across the smaller valleys or where the rock was not suitable for a pressure tunnel, riveted steel pipe encased in concrete and lined with two inches of cement mortar, was laid in a trench just below the natural surface and covered with a protective grassed embankment of earth. This is known as the steel-pipe siphon type, although it is not truly a siphon but rather an inverted siphon. The pipes are from 9 to 11 feet in diameter and are made of steel plates from 7/16 inch to ¾ inch in thickness, riveted together. There are fourteen of these siphons, totaling 6 miles. Provision has been made at the junction of these siphons with the ad-

Harlem Railroad steel-pipe siphon, looking northward toward Sarles tunnel. The Siphon Chamber superstructures are of vitrified paving brick culls with cast concrete-stone trimmings and reinforced-concrete tile roofs. Note the steel towers of the aqueduct electric power transmission-line.

joining aqueduct for three pipes which will eventually be required, although at present only one pipe has been completed.

The cut-and-cover aqueduct and the tunnels are more than big enough for railroad trains to pass through them with ease. The Catskill aqueduct is twice as long as the two Croton aqueducts put end to end. The water which the Catskill aqueduct can carry would be waist deep between the buildings in Fifth Avenue's fashionable shopping district, if flowing at a comfortable walking speed. The water used by New York City each day weighs about eight times as much as its population.

The City Tunnel

From Hill View reservoir, Catskill water is delivered into the five boroughs by a circular tunnel in solid rock reducing in diameter from 15 feet to 14, 13, 12 and 11 feet. The total length of the tunnel is 18 miles. From two terminal shafts in Brooklyn, steel and cast-iron pipe-lines extend into Queens and Richmond, respectively. A 36-inch, flexible-jointed, cast-iron pipe, buried in a trench in the harbor bottom, has been laid across the Narrows to the Staten Island shore, whence a 48-inch cast-iron pipe extends to the Silver Lake reservoir. The total length of this delivery system is over 34 miles. The tunnel is at depths of 200 to 750 feet below the street surface, thus avoiding interference with streets, buildings, subways, sewers and pipes. These depths are necessary, also, to secure

A full-circle panorama of New York City's streets around Madison Square showing Shaft 18 and a portion of the City tunnel in the rock more than 200 feet beneath the surface. Madison Square Garden tower, the Metropolitan tower and the Flatiron Building are easily recognized from left to right.

a substantial rock covering to withstand the bursting pressure of the water inside and afford the requisite watertightness. The waterway of the tunnel is lined throughout with Portland cement concrete.

The City tunnel, which is the longest tunnel in the world for carrying water under pressure, or for any other purpose, was constructed from 25 shafts, including the Downtake shaft at Hill View reservoir, about 4,000 feet apart, located in parks and other places where they interfered very little with traffic. Through twenty-two of these shafts the water is delivered into the street mains. These connections from the tunnel to the mains are made by means of vertical riveted steel pipes (called risers) embedded in concrete in the upper part of each shaft and lined with concrete to prevent corrosion inside. Provision is made for unwatering the tunnel, whenever necessary, for inspection, cleaning or repairs.

Laying the Narrows siphon from Brooklyn to Staten Island. At the left s the clam-shell dredge boat with its scows and at the right the pipe-laying barge and the submerged bridge used to support the pipe-line as it was put together. The barge and bridge were moved forward as the pipes were added to the line so that the pipe-line was paid out like a chain, into the bottom of the trench. Subsequently the pipe was covered over with sand and gravel.

Unusual features in connection with the operation of the tunnel are the bronze riser valves in the shafts, 48 inches and 72 inches in diameter, and the section valves, 66 inches in diameter, also of bronze. The former are located about 100 feet below the top of sound rock and are designed to close automatically in case of an important break in the valve-chamber or in the street mains, causing an abnormally large flow of water. They can also be closed by hand from within the chambers at the shaft tops. The section valves, two in number, are located across the main tunnel, at the bottoms of Shafts 13 and 18, and permit the tunnel to be divided into parts and drained in sections without putting it entirely out of commission.

At Shaft 3, at the northerly end of Jerome Park reservoir, and at Shaft 10, in St. Nicholas park, connections were made to the Jerome Park reservoir and the Croton aqueducts, respectively. Below 24th street, there are connections at each of the shafts, except Shaft 24, to the high-pressure fire service, with electrically-operated valves at the shafts controlled from the fire pumping-stations.

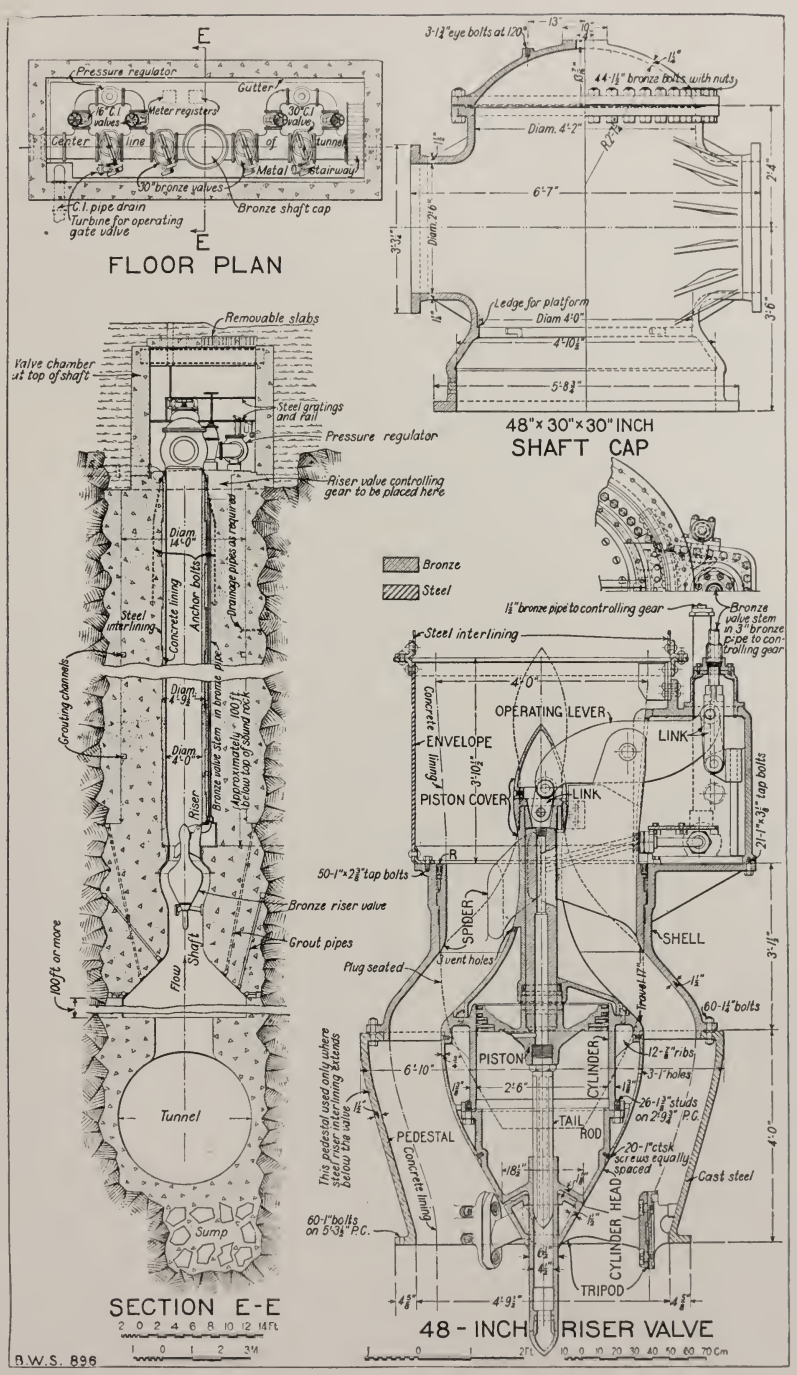
The cost of the portions of the Catskill aqueduct within the City limits, including the tunnel, pipe-lines, appurtenances and Silver Lake reservoir, was $23,000,000.

THE SCHOHARIE DEVELOPMENT

The Schoharie development, on which work is now under way, bears equal importance with the Esopus, inasmuch as each will be called upon to yield upwards of 250 million gallons daily to supply the full carrying capacity, 500 million gallons daily, of the main aqueduct.

Schoharie creek lies north of the Esopus, in the heart and higher section of the Catskill mountains. The new Gilboa dam will be located about four miles northeast from the Grand Gorge station of the Ulster and Delaware railroad, and access to the site is to be had over existing highways. Grand Gorge station is 66 miles by rail from Kingston and 155 miles from New York. It is 120 miles in an air line north of the City Hall and 35 miles west of the Hudson river. The southerly line of Albany county extended westerly would pass directly through the Schoharie reservoir. The tributaries have their source at elevations of nearly 2,000 feet in the localities of Hunter, Windham, Prattsville and Grand Gorge in Greene, Delaware and Schoharie counties. The watershed is similar in character to the Esopus, chiefly steep mountains of shale and sandstone, which are covered with wild forest growth. These streams are flashy, there being large freshets in the spring with very little flow during the summer months. Because of this steep and rocky character, the flow in the streams is a large proportion of the rainfall. Of the 47 inches depth of rainfall in a year on the Esopus watershed, 29.5 inches (63 per cent.) appears as stream flow, while the Schoharie, with only 39.5 inches of rainfall, yields 27.2 inches (69 per cent.) as stream flow. Compared with these, the Croton yields 22.4 inches of stream flow, and the Wachusett watershed of the Boston supply yields but 21.3 inches of stream flow on the average.

While the Esopus flows out of the Catskills through the southerly gateway toward Kingston and the Hudson river, the Schoharie flows out through the northerly portals to the Mohawk river near Amsterdam. It lies at a sufficiently high elevation to enable the flow to be intercepted by a dam at Gilboa, reversing



Sections of a typical shaft and chamber of the City tunnel, with details of a riser valve and shaft cap.

the direction and sending the water through an 18-mile tunnel under the intervening Shandaken mountain range into Esopus creek at Allaben in Ulster county. The water thus diverted will join the water of the Esopus and find its way for 15 miles into the Ashokan reservoir, where it will be available for the main Catskill aqueduct. Thus the Catskill system is extended 36 miles, making a distance of 156 miles from the Gilboa dam to the Silver Lake reservoir on Staten Island.

In the original report of October 9, 1905, it was contemplated that both the Rondout and Schoharie watersheds would be developed to supplement the Esopus, in furnishing the desired 500 million gallons per day. Subsequent borings in the Rondout disclosed such subsurface conditions that to build a dam there would be much more expensive than originally anticipated. On the other hand the accumulation of accurate run-off data in the Catskill region has adequately proved that the safe yield of the Esopus and Schoharie watersheds is higher than originally estimated. So that by placing the dam at Gilboa instead of Prattsville as originally planned, thus increasing the watershed from 226 square miles to 314 square miles, and also increasing storage from 9½ to 20 billion gallons, the Schoharie alone can be depended upon for 250 million gallons per day, which with the Esopus will yield the contemplated 500 million gallons daily.

This amended plan was approved by the Board of Estimate and Apportionment January 31, 1916, and by the State authorities June 6, 1916. The land-taking surveys were begun in July, 1916, and detailed subsurface investigations by borings for the definite location and design of the tunnel and dam were prosecuted in 1916 and 1917, and it is planned that the entire development will be completed in 1924.

The Shandaken Tunnel

Contract 200, for the construction of the Shandaken tunnel, was awarded on November 9, 1917, for $12,138,738.

The Intake is located about 3½ miles north of the Village of Prattsville. From here the tunnel extends in a generally southeasterly direction until just south of the Village of Allaben, where it discharges into the Esopus creek. The tunnel is horseshoe in section, concrete lined, with inside dimensions of 11 feet 6 inches in hight by 10 feet 3 inches in width, and provides for a uniform slope of 4.4 feet per mile except for the northerly 3½ miles, which is depressed, making this portion a pressure tunnel. Seven intermediate shafts are provided, the aggregate depth of shaft being 3,238 linear feet, the maximum depth of a single shaft being 630 feet. The minimum distance between shafts is 1.3 miles, the maximum 2.7 miles. All shafts are circular and will be concrete lined, surmounted with shaft houses built of native stone. The upper portion of the Intake shaft will be so constructed that it will act as a Venturi meter and the building over this shaft will also contain the control gates and the keeper's residence.

After the award of the contract, work was begun, and to June 1, 1919, there had been excavated 2,310 feet, or 71 per cent. of shaft, and 63 per cent. of the concrete lining in the shafts had been placed.

This tunnel construction includes about 600,000 cubic yards of rock excavation, 100,000 cubic yards of earth excavation, 200,000 cubic yards of concrete masonry and 445,000 barrels of Portland cement.

The Gilboa Dam

Contract 203, for the construction of Gilboa dam, was advertised and bids were opened on May 14, 1919; all bids were rejected and the contract is now being advertised, the bids to be opened on June 19, 1919. The work is to be completed within 5½ years after the service of notice to begin work, or approximately at the end of 1924.

The construction includes about 396,000 cubic yards of earth excavation, 92,500 cubic yards of rock excavation, 617,000 cubic yards of refilling and embanking, 436,000 cubic yards of masonry and 480,000 barrels of Portland cement. The dam is composed of two parts—an overfall masonry portion about 1,300 feet in length and having a maximum hight of about 160 feet with the crest at Elevation 1,130 feet above sea-level, and an earth section at Elevation 1,150 feet, with core-wall, approximately 1,000 feet long. Along the down-stream toe of the dam there is to be constructed a channel for collecting and conveying the overflow flood waters into the present channel of Schoharie creek below the dam.

The 1,300-foot overfall portion of the dam will be constructed of cyclopean masonry, being large blocks of stone buried in concrete; the water side will be faced with natural stone down as far as the water will be drawn; the down-stream face of the masonry section will be made in large steps from 10 to 20 feet in tread and rise, all faced with natural stone with the overfall corners composed of the largest possible stones set on edge, thoroughly anchored. This portion is founded on solid rock.

The 1,000-foot earth section for the left or west bank is required because of the pre-glacial gorge, which swings under the mountainside; the masonry section, where it joins the earth section is flanked at right angles both up-stream and down-stream by long, high and heavy retaining-walls, faced with natural stone; these walls will intercept the long earth slopes of the earth section; beyond them the masonry section of the dam will taper into a core-wall which will be continuous throughout the length of the earth section and extend into the mountainside; the earth section in places will extend above 100 feet in hight and will be upwards of 400 feet in thickness at the base; the water-side slope of the earth embankment will be paved with heavy stone.

The Schoharie Reservoir

The Schoharie reservoir will serve both as a diverting and as a storage reservoir. It will store 20 billion gallons, so that a large part of the storage for the Schoharie has been provided in the Ashokan reservoir. It holds only 0.14 of the amount of the total flow of the Schoharie for an average year, while the Ashokan holds 1.03 times the flow of Esopus creek. The tunnel was therefore built large enough so that in times of plenty the water can be rushed through to Ashokan at a rate of 600 million gallons a day, more than twice the normal rate of contemplated draft from Schoharie. The Ashokan and Schoharie reservoirs combined will hold 0.53 of the combined Schoharie and Esopus yearly flow, while if we include the Kensico reservoir the Catskill system will have available storage of 177 billion gallons, or 0.62 of the average yearly flow of all its contributing streams.

The reservoir is approximately five miles long and about one mile in maximum width, reaching from Gilboa to Prattsville, the former being the only village dis-

View looking southerly at site of Gilboa dam, showing Village of Gilboa, and portion of Schoharie Creek valley. The church spire is at Elevation 1125, five feet below the reservoir flow line and on the approximate center line of the dam.

turbed. No railroad will be disturbed, and the highways to be relocated require 12.4 miles to replace 13.6 miles submerged. As at Ashokan, the City has acquired a marginal strip around the shore line for sanitary protection of the water.

CATSKILL WATER

Catskill water is a surface-water collected in a thinly populated region from hills and mountains composed entirely of shale and sandstone rock. The result is a water exceedingly soft and free from pollution. It is very much softer than the ground-water obtained from the wells of Long Island and also superior in this respect to the Croton water. Certain steps are taken to safeguard and even improve the natural excellent quality of the water.

Marginal strips of land around the reservoirs were obtained and have been to a large extent cleared of undesirable growth and dead wood and have been reforested. This will tend to prevent erosion of the shores and gives such control of the ground adjacent to the reservoirs that contamination and pollution may be avoided.

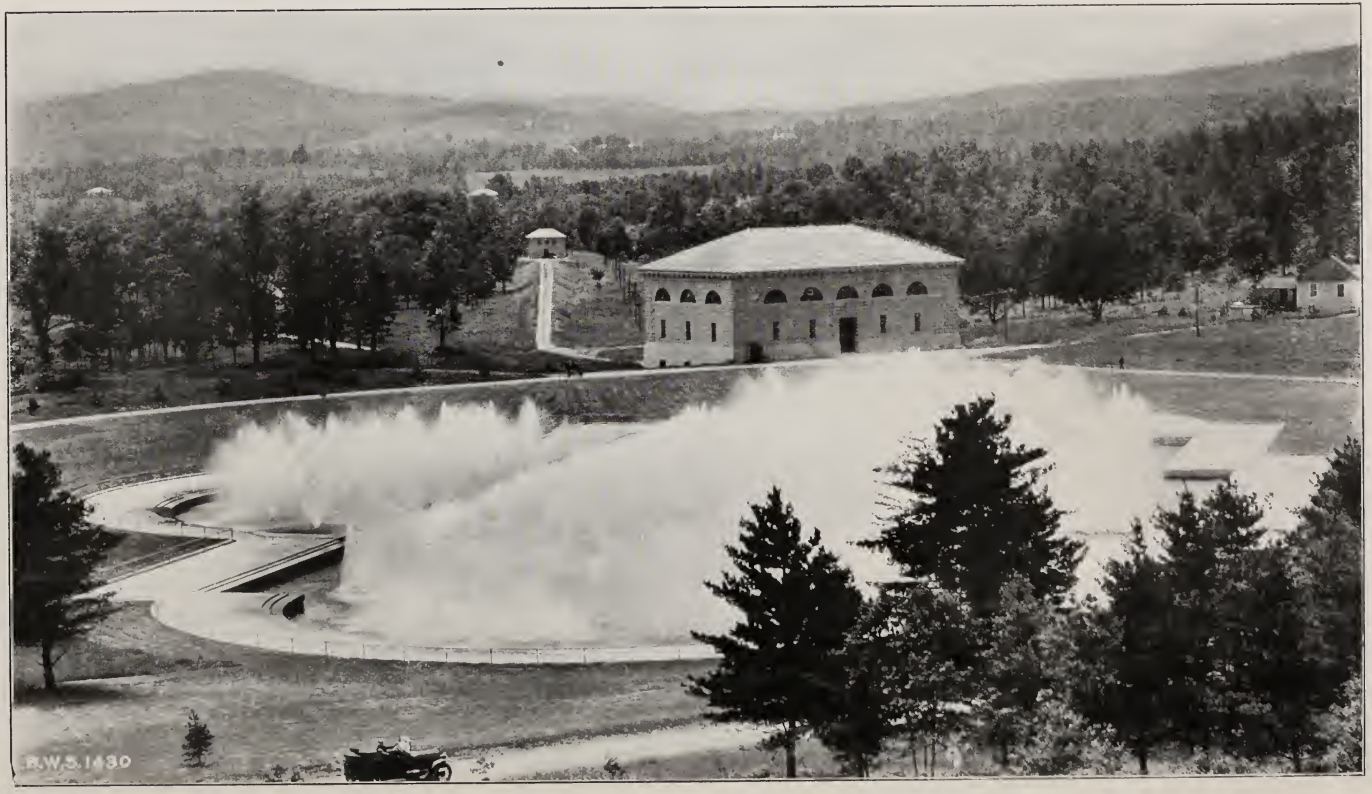
Much attention has been paid to the pollution of tributary streams, especially near communities where there is a considerable influx of summer visitors. The coöperation of communities has been obtained and the sanitary condition of hundreds of premises has been improved, resulting not only in local benefit but also in safeguarding New York City's supply.

Storage.—The available storage of water when the three large reservoirs, Ashokan, Schoharie and Kensico, are full, is 177 billion gallons. The result of the long storage which the water receives is that sedimentation, bleaching by the sun, oxidation by the winds and sterilization by natural processes go on more or less continuously.

The temperature, turbidity, suspended microscopic growths and other qualities of the water in a large reservoir vary at different depths and at different seasons of the year. The gate-houses through which the water is drawn from the reservoirs into the aqueduct are so arranged that the water may be drawn from the depth furnishing the most desirable water. Furthermore, a dividing weir across Ashokan reservoir makes it possible to draw water from the basin furnishing the best water at any given time.

Temperature.—The temperature of the water in the Ashokan reservoir during the winter months is quite constant at all depths. The surface-water in the fall is cooled by the atmosphere, and as it becomes colder than the water beneath a vertical circulation takes place whereby the colder and heavier water goes to the bottom, resulting in what is termed a turnover. During the middle of winter the general temperature is as low as 33 degrees Fahrenheit. During the summer months, however, there is practically no vertical circulation when the upper layers are being warmed by the sun. During the summer the water at the bottom of the reservoir reaches a temperature of about 60 degrees Fahrenheit while the water near the surface generally is much warmer.

The water taken into the aqueduct after aeration at Ashokan has an average temperature of 50 degrees Fahrenheit in the winter being as low as 33 degrees Fahrenheit and in the summer never reaching over 68 degrees Fahrenheit. The



Ashokan aerator and the beginning of the Catskill aqueduct. The large building is the Screen chamber, at which the Standard aqueduct begins. Following the aqueduct embankment, one comes first to the Gaging chamber and, to the left, the two chambers of the Esopus steel-pipe siphon. The Lower gate-chamber is just out of the picture at the right.

water as it passes through the aqueduct is everywhere in a closed duct and is not only protected from interference of ice, snow and pollution, but is thoroughly insulated by the surrounding concrete, rock and earth. Thus it is that in the length of a day, which is the time which it takes the water leaving the Ashokan reservoir to reach the City, the temperature of the water is not changed while it is in the aqueduct. The water flows through the aqueduct at about a brisk walking speed, that is, from three to four miles per hour.

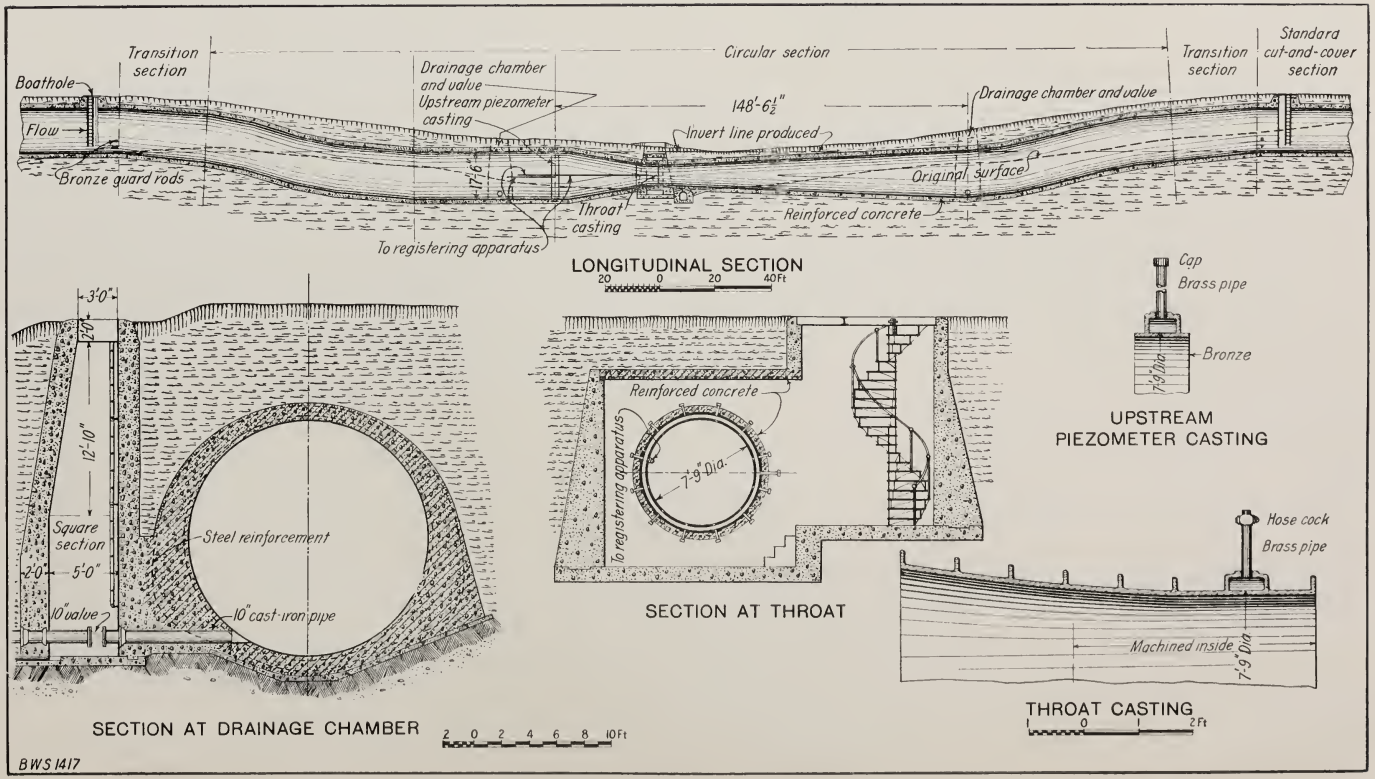
Aeration.—Along the aqueduct, just below Ashokan and Kensico reservoirs, provision has been made for jetting the water into the air in fine spray, thus permitting thorough admixture of oxygen from the atmosphere and removal of objectionable gases and the breaking down of other matters causing tastes and odors. The two aerators are substantially alike and are great fountain basins, approximately 500 feet long by 250 feet wide, each containing about 1,600 nozzles, through which jets of water are thrown vertically into the air.

Removal of Turbidity.—At a number of places in the Catskill watersheds there are banks of very fine clay-like earth on the hill slopes or along the streams and margins of the reservoirs. Under certain conditions of storm or very rapid run-off of water some of this earth is carried into the streams and by them into the reservoirs, making the water somewhat turbid. Most of this material causing the turbidity settles in the reservoirs during the period of storage, but at very infrequent intervals some of the most finely divided particles find their way into the aqueduct. Provision has been made for eliminating when necessary the remaining turbidity by a coagulating plant located about two miles above Kensico reservoir. The process consists of the introduction into the water of very small quantities of alum or sulphate of alumina. It reacts with the minute quantities of lime naturally in the water, forming a flakey precipitate; that is, it forms flakes resembling unmelted snow flakes, which being heavier than the water, completely settle to the bottom during the storage period in Kensico reservoir. During the settling the precipitate intercepts and carries down with it the finely divided particles held in suspension, thus completely relieving the water of its turbidity.

Sterilization.—In order to eliminate the very small proportion of pathogenic or harmful bacteria which may occur among the vastly larger proportion of harmless microscopic life found in the water, the water is sterilized by the introduction of chlorine, a very active oxidizing agent. This takes place in the Screen chamber after the water drawn from Kensico reservoir has been aerated. The chlorine, normally a gas, is obtained, compressed to a liquid state, and delivered to the point of use in containers holding 100 pounds each. The chlorine, as it is released from the containers, reverts to the gaseous state and is led through control and measuring devices, and dissolved in water. The resulting solution is fed by rubber tubing which is not affected by the corrosive action, to various depths of the water in the aqueduct, where it is almost instantly disseminated. The control of the gas through the chlorinating apparatus is so complete that only sufficient gas is introduced to effect the desired sterilization, all the gas being taken up by reaction on the organic life or other foreign material in the water.

Filtration.—Provision for a filtration plant was made by the acquisition of 315 acres of land and by building a connection chamber to the aqueduct about two miles below Kensico reservoir.

Measurement.—Measurements of the amount of rainfall at various selected places throughout the watersheds and the flow of the streams are made by stand-



One of the Venturi meters in the Catskill aqueduct.

ard methods for the purpose of determining the amount of water available. Besides this the amount of water passing through the aqueduct is measured, first just after its entrance from Ashokan reservoir, then before entrance into Kensico reservoir, again as it leaves this reservoir, and finally upon its entrance into the City tunnel after passing through Hill View reservoir. These measurements are made by means of Venturi meters accurately constructed as parts of the aqueduct. At these points the aqueduct is circular in section and one short portion is built with a greatly reduced cross-section, similar to the contraction of an hour glass. Ap-

Peak Gaging chamber in the Catskill aqueduct south of Peak tunnel.

paratus attached to these meters is so designed as to accurately record and register the amount of water passing. The three meters installed above the City are the largest ever constructed, each being 410 feet long and built of reinforced concrete. The contracted portion consists of a bronze casting and is 7 feet 9 inches in diameter. Provision is also made at gaging chambers for obtaining the velocity of the water by means of current meters lowered into the aqueduct.

EXPLORATIONS AND SURVEYS

In order that the Catskill aqueduct might be most safely and economically located, extensive surveys and subsurface explorations were made of both topo-

graphical and geological character. It was necessary for the Board's engineers to make about 3,000 miles of line surveys, besides the very extensive topographical surveys of the reservoir sites and the final location of the aqueduct.

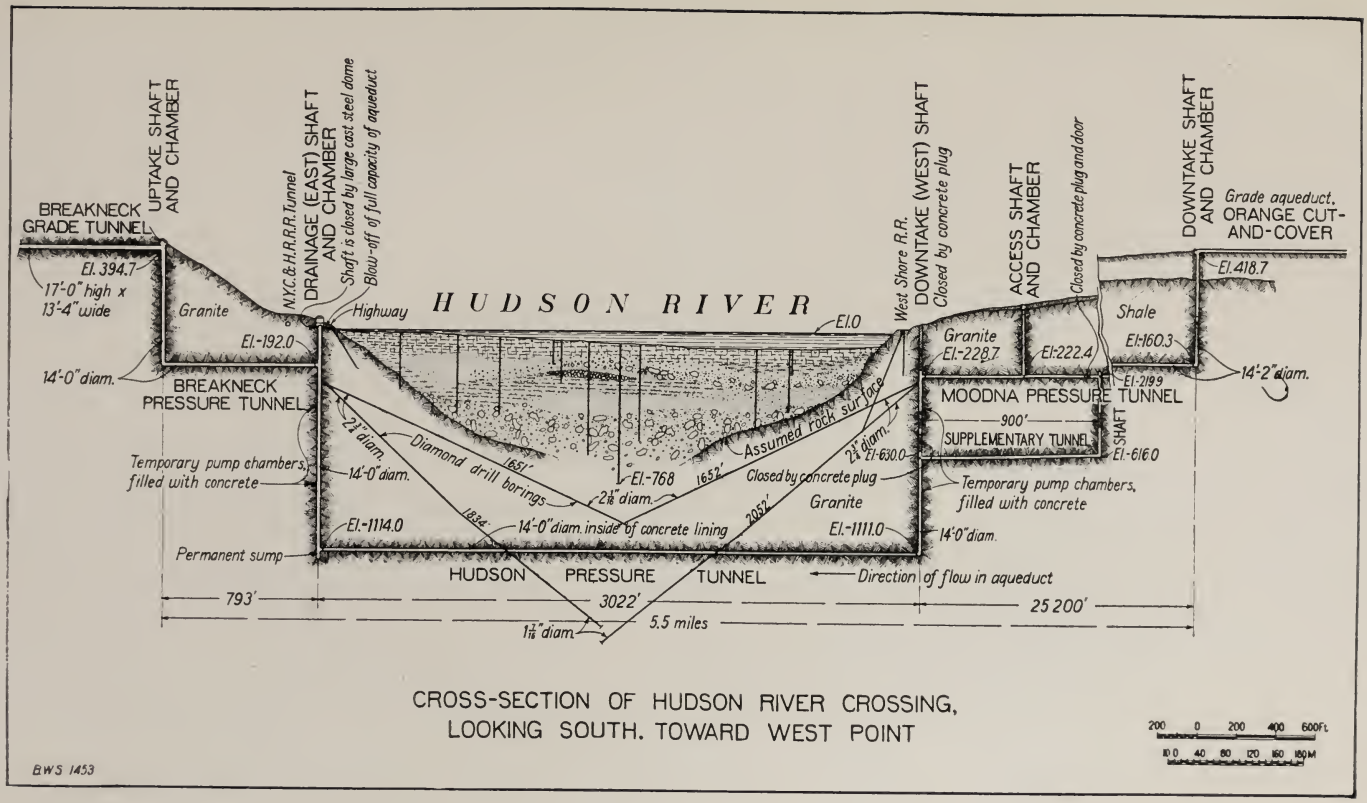
For determining the exact location of the deep valley crossings, geological explorations by means of borings into the rock, with diamond and shot drills, were necessary, and were carried on under the immediate supervision of skilled, practical geologists. Such explorations were also made for the locations of the dams and for other features of the work. In the aggregate, these borings amounted to 240,000 feet, or 45 miles.

Before the Board began its work the nature of the Hudson river bed from Albany to the sea, and the depth of the bed-rock beneath it were matters of conjecture. Definite, dependable information must be had; therefore, the Board began almost immediately after preliminary organization of its Engineering bureau, investigations to determine where the river could be crossed safely and economically. A number of possible crossings were explored, but all of them developed great difficulties, excepting the one at the northerly end of the Highlands, where a band of granite crosses the valley, outcropping in Storm King mountain on the west side and Breakneck mountain on the east side. Endeavors were made by boring from scows on the surface of the river to determine the depth to the bed-rock, but this work proved tedious and expensive, and at best could give information at only a few points. Winds, tides and traffic and the severe winter weather all militated against this method of exploration. It was therefore determined to start a test shaft on each bank as close to the edge of the river as was practicable, and when a suitable depth had been attained, to drill from a chamber in the side of the shaft inclined bore holes out under the river. From each shaft two holes were drilled. In each case the first hole was inclined rather steeply downward so as to reach the center of the valley at a depth about 1,500 feet below the surface of the river. The holes were each about 2,000 feet long. Many interesting difficulties were overcome and samples of the rock obtained for the whole distance. The second holes were then driven at a much flatter slope, taking the chance that they might possibly run out of the rock before reaching the center of the valley. These two holes, however, were wholly in rock and intersected at a depth of about 950 feet. Meanwhile a drilling from a scow near the center of the river had reached a depth of 768 feet without entering the bed-rock, although having developed evidences of being near the rock, when the hole was lost through accident. With this information in hand it was determined to locate the tunnel across the river at a depth of 1,114 feet below the river surface, being assured that at the shallowest place it would have somewhat more than the necessary minimum of 150 feet of sound rock above its roof.

Some deep and difficult drilling was required also in connection with the location of the City tunnel and its shafts, particularly in the lower east side of Manhattan Island, where the old bed of the East River was crossed, which lies west of the present location of that river.

THE COST

For surveys, real estate, construction, engineering and general supervision, and all other items except interest on the bonds, the total cost of the completed Catskill system will be about $177,000,000, of which $22,000,000 is for the Schoharie works. To January 1, 1919, $139,800,000 had been expended.



CROSS-SECTION OF HUDSON RIVER CROSSING, LOOKING SOUTH, TOWARD WEST POINT

BWS 1453

Board of Water Supply Forces

Bureau	*Jan. 1, 1919	Maximum at Various Dates
Commissioners	3	3
Administration bureau	33	66
Police bureau	47	387
Engineering bureau:		
Chief Engineer and staff	8	13
Headquarters department	83	260
Reservoir department	95	236
Northern Aqueduct department	2	630
Southern Aqueduct department	16	318
City Aqueduct department	73	269
Total, Engineering bureau	277	
Total, Board of Water Supply	360	
Engineering bureau; maximum force at any one time		1,348
Maximum total forces of the Board		1,757

*Including 57 employees absent on Military or Naval duty, and 4 employees on civilian duties connected with the war

Statistics of Ashokan, Kensico and Schoharie Reservoirs

	Ashokan	Kensico	*Schoharie
Capacity, total	130,000,000,000 gallons	38,000,000,000 gallons	22,000,000,000 gallons
Capacity, available	128,000,000,000 gallons	29,000,000,000 gallons	20,000,000,000 gallons
Water surface	12.8 sq. miles= 8,180 acres	3.5 sq. miles=2,218 acres	1.83 sq. miles=1,170 acres
Land acquired	23.8 sq. miles=15,222 acres	7.0 sq. miles=4,500 acres	3.72 sq. miles=2,372 acres
Elevation of top of dam, above tide	610 feet	370 feet	1,130 feet
Length of reservoir	12 miles	4 miles	5 miles
Length of shore line	40 miles	30 miles	12 miles
Length of dams and dikes	5½ miles	3,300 feet	2,300 feet
Main dam:			
total length	4,650 feet	1,825 feet	2,300 feet
length of masonry portion	1,000 feet	1,825 feet	1,300 feet (Earth, 1,000 feet)
hight (maximum)	252 feet	307 feet	160 feet
thickness at base (maximum)	190 feet	235 feet	165 feet
thickness at top (minimum)	23 feet	28 feet	15 feet
Width of reservoir:			
maximum	3 miles	3 miles	4/5 mile
average	1 mile	1 mile	2/5 mile
Depth of reservoir:			
maximum	190 feet	155 feet	140 feet
average	50 feet	52 feet	58 feet
Villages submerged	7	1	1
Permanent population of submerged area at beginning of work	2,000	500	350
Cemeteries removed	32	none	7
Bodies reinterred	2,800	none	1,330
Railroad relocated	11 miles	none	none
Highways discontinued	64 miles	14.8 miles	13.6 miles
Highways built	40 miles	15.1 miles	12.4 miles
Highway bridges built	10	4	2
Earth and rock excavation	2,500,000 cubic yards	1,400,000 cubic yards	488,500 cubic yards
Embankment	7,300,000 cubic yards	2,010,000 cubic yards	617,000 cubic yards
Masonry	900,000 cubic yards	965,000 cubic yards	436,000 cubic yards
Cement	1,200,000 barrels	897,000 barrels	480,000 barrels
Maximum number of men employed	3,000	1,500	.....

*Construction not yet begun

Land Acquired

	Acres	Square Miles
Schoharie reservoir	2,372	3.7
Shandaken tunnel	80	.1
Ashokan reservoir	15,222	23.8
Kensico reservoir	4,500	7.0
Aqueduct, Ashokan to City line	2,279	3.6
Filter site	315	.5
Hill View reservoir	164	.2
Silver Lake reservoir and City tunnel	166	.3
Total	25,098	39.2

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